A Probabilistic Approach To Estimating Exposure Potential For Children Playing On Diazinon-Treated Residential Soil

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ABSTRACT

Diazinon is registered for soil treatment in residential areas to control the pupae of various pest species. It is probable that young children playing on treated soil in these areas can be exposed to some diazinon residues through incidental ingestion of, or through dermal contact with, the soil. The conventional approach to quantifying this type of exposure potential is to select conservative point estimates for the underlying exposure scenario. These point estimates are actually extremely improbable and yield highly conservative intake or uptake estimates that most likely overestimate the risk involved. The Monte Carlo-based probabilistic approach undertaken in this study is considered a more realistic alternative wherein probability distributions for the various key exposure factors (e.g., body weight, body surface, skin-soil loading, soil concentration, soil ingestion rate, etc.) were used instead of their point estimates. Preliminary results indicated that the point estimates of dermal uptake and oral intake of diazinon from treated soil were, respectively, ≥ 6 and ≥ 20 times the 95*th* percentile upper bounds calculated by the probabilistic model.

Table 1. Literature Data Pertinent to This Case Study (for Children of Age 2)

Exposure Parameter	Study/Report	Mean/Fair Estimate(s)	Range	Likely-Used Extreme Value
diazinon soil level, ppm	Fairchild, 1983[a]	10.0	1.2 - 49.6	49.6
	Schneider *et al.*, 1994[b]	10.6	3.0 - 16.1	
skin-soil loading, mg/cm^2	USEPA, 1992[c]	0.2	0.2 - 1.5	1.5
	Thompson *et al.*, 1992	0.5 - 1.5		
dermal absorption, %	Wester *et al.*, 1993[d]	3.85 ± 2.16		≥ 6.0
fraction of skin exposed	USEPA, 1992a[e]	0.05 - 0.25		
	Thompson *et al.*, 1992	0.12 ± 1.65	0.03 - 0.55	0.55
soil ingestion, mg/day	Whitmyre *et al.*, 1992	200	10 - 1,000	
	USEPA, 1990[f]	200	10 - 10,000+	> 2,000
body weight (BW), kg	USEPA, 1990[g]	12.6	9.0 - 16.2	9.0
body surface, m^2	Costell, 1966	= (4 x BW + 7)/(BW + 90)		0.43

[a] samples (n = 40) taken in Santa Clara County after watering-in and within 1 day of treatment with 0.12 lb emulsifiable concentrate (in 3 gallons of water) per 1,000 sq ft of soil ; only summary statistics were given.

[b] samples (n = 9) taken in Sacramento County and in a manner similar to that above by Fairchild (1983).

[c] per event (treated as per day, since children under age 12 reportedly spend an average of 1 hr/day outdoors).

[d] the extreme value was calculated from adding 1 s. d. to the highest mean of 3.85% observed in the study.

[e] the suggested fraction for winter, spring, summer, and fall are 5, 10, 25, and 10% of the skin, respectively.

[f] including children with pica; otherwise, a normal upper bound is estimated to be 800 - 1,000 mg/day.

[g] the 5*th* and 50*th* percentiles for a girl of age 2 are reportedly 10.4 and 12.6 kg, respectively; the 1*st* and 99*th* percentiles are estimated to be 9.0 and 16.2 kg, respectively.

THE WORST-CASE APPROACH

(For a Two-Year-Old Girl)[a,b]

Uptake = {(soil concentration) * (skin-soil loading) * (total skin surface) * (fraction of skin exposed) * (dermal absorption)} ÷ (body weight)

= {(49.6 ηg/mg) * (1.5 $mg/cm^2/day$) * (4,343 cm^2) * (55.0%) * ($\geq$ 6.0%)} ÷ (9.0 kg)

$\geq$ 1.2 μg per kg of body weight

Intake = {(soil concentration) * (soil ingestion rate) * (oral absorption)} ÷ (body weight)

= {(49.6 ηg/mg) * (> 2,000 mg/day) * (100%)[c]} ÷ (9.0 kg)

> 11.0 μg per kg of body weight

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[a]for likely-used extreme values, see Table 1.

[b]also for adults gardening in treated soil, since a two-year-old child has the greatest body surface area per unit of body weight and is likely to have the worst mouthing behavior.

[c]as a default percentage for oral absorption.

THE PROBABILISTIC APPROACH

The simulation performed in this case study simply treated each (key) input exposure parameter as a random variable. It then relied on the computer to draw one value for each of these variables, and finally to compute a single dosage estimate using the values randomly selected (and, if any, also those that were fixed for nonrandom variables). This process was repeated 10,000 times to generate a representative distribution of the values simulated for the dosage in question. This set of 10,000 values was then used to provide a reasonable high-end estimator (*e.g.*, the 90*th* or 99*th* percentile) for the dosage in question. There were 10 trials performed to ensure both the randomness of value selection and the precision of high-end estimation.

The random variables were each pre-assigned a range of values whose selection during each simulation run was governed by some pre-defined probabilistic rules. Many probabilistic rules (*i.e.*, the assumed probability distributions and fixed values) used in the simulation were based on those available in the literature. The actual simulation was implemented using a computer software called *Crystal Ball* (1993).

RESULTS AND DISCUSSION

The input variables used for simulation, along with their probability distribution or fixed value where applicable, are provided in Table 2. The simulation results for daily dermal uptake and for daily oral intake are presented in Tables 3 and 4, respectively.

For a two-year-old girl playing in treated soil within 1 day post-application, the 95*th* percentile simulated for the daily uptake dosage averaged 0.2 μg per kg of body weight (Table 3). The highest value simulated for this dosage based on all 10 trials was 0.9 μg/kg, less than the worst-case uptake by 25% or more. The average 95*th* percentile of the daily dosage simulated for oral intake was 0.6 μg/kg (Table 4). The highest value simulated for this dosage was 4.6 μg/kg, less than the worst-case intake by 58% or more.

These findings suggest that the worst-case scenarios considered earlier will rarely, if ever, happen in real life. Literally, it means that many more simulation runs than 100,000 (*i.e.*, 10 trials x 10,000 runs/trial) are needed before there will be one success attained of having *all* the extreme values selected *simultaneously* for calculation of the dosage in question.

Table 2. Variables and Distributions Used in Simulation

Parameter	Probability Distribution	Mean ± S. D.[a]	Range	Source[b]
	A. For Dermal Uptake of Diazinon in Soil			
soil residues, ppm	lognormal	10.5 ± 1.68	1.0 - 50.0	*A*, *B*
fraction of skin exposed	lognormal	0.2 ± 1.40	0.05 - 0.65	*C*, *D*
skin-soil loading, mg/cm^2	uniform		0.5 - 1.5	*C*, *D*
dermal absorption, %	uniform		3.85 - 10.3	*E*
body weight (BW), kg	normal	12.6 ± 1.2	9.0 - 16.2	*F*
body surface, m^2	= (4 x BW + 7)/(BW + 90)		0.43 - 0.68	*G*
	B. For Oral Intake of Diazinon in Soil (Assuming 100% Absorption)			
soil residues, ppm	lognormal	10.5 ± 1.68	1.0 - 50.0	*A*, *B*
soil ingestion, mg/day	lognormal	200 ± 1.71	10 - 10,000	*F*, *H*
body weight, kg	normal	12.6 ± 1.2	9.0 - 16.2	*F*

[a] the 50*th* percentile was used as the mean body weight for girls of age 2; for a lognormal, the above geometric mean and standard deviation (s. d.) after logarithmic transformation were used to describe the underlying (normal) distribution; for a uniform, the lowest and highest were used; and where necessary the required s. d. was estimated from setting a reported extreme value, which was not necessarily the upper limit, at the 99*th* percentile.

[b] (*A*) Fairchild, 1983; (*B*) Schneider *et al.*, 1994; (*C*) Thompson *et al.*, 1992; (*D*) USEPA, 1992a; (*E*) Wester *et al.*, 1993; (*F*) USEPA, 1990; (*G*) Costell, 1966; and (*H*) Whitmyre *et al.*, 1992.

Table 3. Uptake Dosages Simulated for Diazinon in Soil[a]

Percentile	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0.0%	0.003	0.005	0.004	0.005	0.004
2.5%	0.014	0.014	0.014	0.014	0.014
5.0%	0.017	0.018	0.018	0.018	0.018
50.0%	0.063	0.062	0.061	0.061	0.062
95.0%[b]	0.208	0.204	0.207	0.202	0.208
97.5%	0.262	0.252	0.262	0.253	0.254
100.0%	0.745	0.821	0.696	0.713	0.761

Percentile	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10
0.0%	0.004	0.004	0.004	0.003	0.004
2.5%	0.014	0.014	0.014	0.014	0.015
5.0%	0.018	0.017	0.018	0.018	0.018
50.0%	0.061	0.062	0.062	0.062	0.061
95.0%[b]	0.205	0.204	0.203	0.203	0.201
97.5%	0.260	0.257	0.249	0.252	0.248
100.0%	0.947	0.795	0.757	0.821	0.699

[a]in μg/kg/day for a two-year-old girl playing in soil within 1 day post-application; see text (under The Worst-Case Approach) for basic algorithm of dosage calculation; and each trial was comprised of 10,000 simulation runs.

[b]this simulated 95*th* percentile averaged over the 10 trials is suggested for use as the dosage for risk assessment.

Table 4. Intake Dosages Simulated for Diazinon in Soil[a]

Percentile	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0.0%	0.009	0.008	0.011	0.008	0.009
2.5%	0.037	0.037	0.038	0.037	0.037
5.0%	0.048	0.047	0.047	0.048	0.049
50.0%	0.165	0.165	0.167	0.166	0.168
95.0%[b]	0.576	0.583	0.560	0.572	0.583
97.5%	0.725	0.721	0.706	0.731	0.730
100.0%	2.489	2.128	4.087	3.263	2.217

Percentile	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10
0.0%	0.010	0.007	0.013	0.009	0.010
2.5%	0.038	0.038	0.038	0.038	0.037
5.0%	0.048	0.047	0.049	0.048	0.047
50.0%	0.168	0.163	0.171	0.167	0.167
95.0%[b]	0.573	0.561	0.586	0.584	0.578
97.5%	0.733	0.722	0.740	0.737	0.734
100.0%	2.090	4.569	2.880	2.327	4.130

[a]in µg/kg/day for a two-year-old girl playing in soil within 1 day post-application; see text (under The Worst-Case Approach) for basic algorithm of dosage calculation; and each trial was comprised of 10,000 simulation runs.

[b]this simulated 95*th* percentile averaged over the 10 trials is suggested for use as the dosage for risk assessment.

In accord with USEPA's guidelines (1992b), a 95*th* percentile value was proposed here to serve as a reasonable upper-bound exposure estimate for this and other pesticide exposure assessments using the Monte Carlo simulation technique.

The results presented indicate that the conservatism built into the worst-case model for oral intake *can be* substantially greater than that built into the worst-case model for dermal uptake, *depending upon the assumptions and extreme values used.* The worst-case value calculated for oral intake is $\geq$ 20 times more conservative (greater) than the 95*th* percentile upper-bound estimated from the 10 simulation trials. On the other hand, the uptake value under the worst-case model is only $\geq$ 6 times greater than the 95*th* percentile upper-bound simulated.

As demonstrated here, Monte Carlo simulation can be a powerful tool for expressing the conservatism inherent in the conventional approach to pesticide exposure assessments. However, this probabilistic approach is not without methodological limitations. It requires detailed input data which are frequently unavailable. Like any analytical model, it also can yield misleading results if the analysis is based on poor data. Monte Carlo simulation thus should be used only when there are credible or acceptable distribution data for most, if not all, of the key variables in question.

There may also be a situation in which some conservatism may need to be incorporated into a Monte Carlo simulation. To some extent, this can be accomplished by restricting the range of values permissible for their random selection. A case in point is the range restricted here for skin-soil loading. As shown in Table 2, the lowest value used for this variable was 0.5 mg/cm^2, which is more than twice the (best) average of 0.2 mg/cm^2 reported by USEPA (1992a). This range restriction was deemed appropriate here because the soil treated with diazinon could be of the type that would have a higher skin-soil adherence property. In accordance with the assumption made by Thompson *et al.* (1992), skin-soil loading was assigned here a uniform distribution wherein the upper limit (1.5 mg/cm^2) would have the same probability of being selected as would any other value within the range.

In this case study, percutaneous absorption of diazinon was likewise assigned conservatively a uniform distribution ranging upward from the highest mean (3.85%) reported in the study by Wester *et al.* (1993) to three standard deviations from this mean. For these reasons, the degree of conservatism built into the worst-case model for dermal uptake might have been underestimated here.

The objective of this case study was to demonstrate the application of Monte Carlo simulation in pesticide exposure assessments. In future simulation where the intent is to actually determine dosages for a more specific exposure scenario, perhaps the ranges and the probability distributions for soil residues and skin-soil loading (and for other key parameters as well) should be based on data from more relevant and more recent studies.

Sensitivity analyses from *Crystal Ball* indicated that some input random variables had more influence over the intake and uptake simulation than did other input variables. As expected, these more influencing input parameters included dermal absorption, fraction of skin exposed, soil concentration, skin-soil loading, and soil ingestion rate. It was hence for these parameters that credible input distribution data were especially important and necessary in this simulation.

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Schneider F, Hernandez BZ, Benson C, Dong MH, Ross JH (1994). Dislodgeable diazinon residues from treated soil and turf. HS-1693. Worker Health and Safety Branch, California Department of Pesticide Regulation [*under review*].

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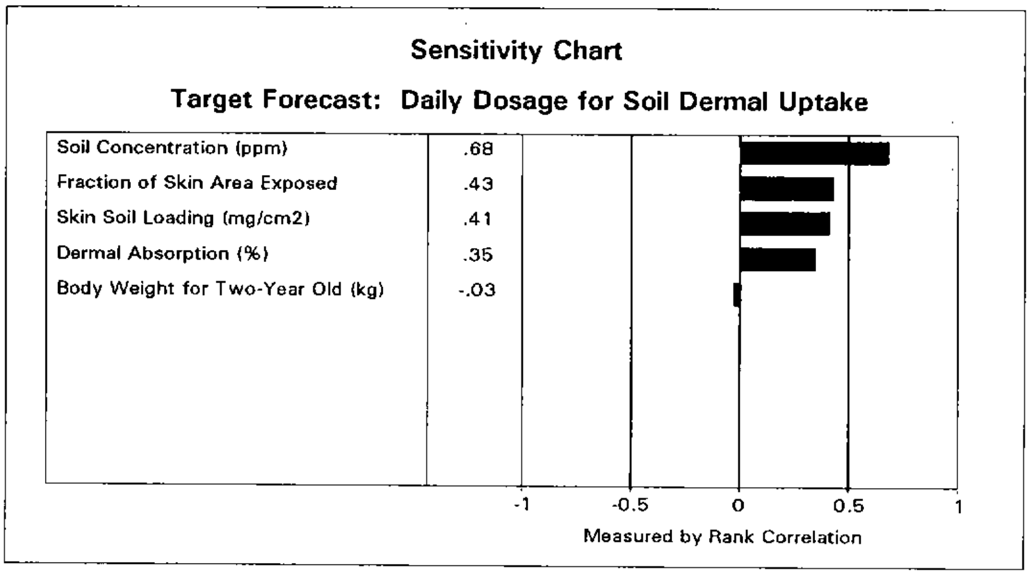
Appendix: *Examples of Simulation Results*

Simulation *trials* in the attached program output are referred to as simulation *runs* in the text. A *trial* in the text on the other hand is referred to as a *batch* of simulation runs from which a percentile distribution of the outcome is generated.

The formulae for estimating the mean (M_{LN}) and the standard deviation (SD_{LN}) of a lognormal distribution from using the geometric mean (M_g) and the geometric standard deviation (SD_g) in the simulation program (*Crystal Ball*) are as follows:

$$M_{LN} = \mathrm{Exp}\{\ln(M_g) + [\ln(SD_g)]^2/2\}; \text{ and}$$

$$SD_{LN} = (M_{LN})\{\mathrm{Exp}([\ln(SD_g)]^2) - 1)^{0.5}\}.$$

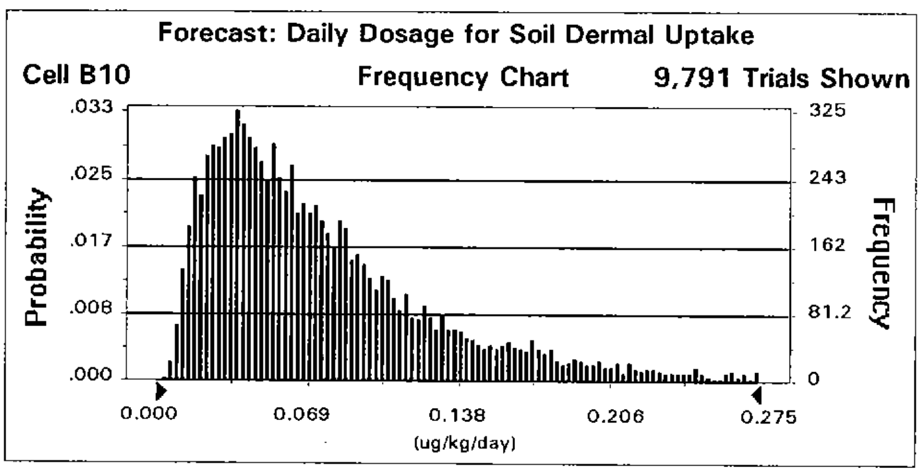

Sensitivity Chart
Target Forecast: Daily Dosage for Soil Dermal Uptake
Soil Concentration (ppm)
.68
Fraction of Skin Area Exposed
.43
Skin Soil Loading (mg/cm2)
.41
Dermal Absorption (%)
.35
Body Weight for Two-Year Old (kg)
-.03
-1
-0.5
0
0.5
1
Measured by Rank Correlation

Forecast: Daily Dosage for Soil Dermal Uptake **Cell: B10**

Summary:

Display Range is from 0.000 to 0.275 (ug/kg/day)
Entire Range is from 0.003 to 0.745 (ug/kg/day)
After 10,000 Trials, the Std. Error of the Mean is 0.001

Statistics:	Value
Trials	10000
Mean	0.081
Median (approx.)	0.063
Mode (approx.)	0.036
Standard Deviation	0.067
Variance	0.004
Skewness	2.532
Kurtosis	13.917
Coeff. of Variability	0.820
Range Minimum	0.003
Range Maximum	0.745
Range Width	0.742
Mean Std. Error	0.001



Forecast: Daily Dosage for Soil Dermal Uptake (cont'd) **Cell: B10**

Percentiles:

Percentile	(ug/kg/day) (approx.)
0.0%	0.003
2.5%	0.014
5.0%	0.017
50.0%	0.063
95.0%	0.208
97.5%	0.262
100.0%	0.745

End of Forecast

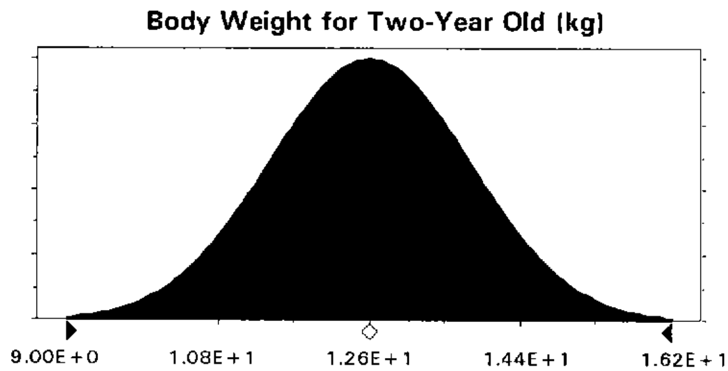
Assumptions

Assumption: Body Weight for Two-Year Old (kg) **Cell: B3**

Normal distribution with parameters:

Mean	1.26E+01
Standard Dev.	1.20E+00

Selected range is from 9.00E+0 to 1.62E+1
Mean value in simulation was 1.26E+1



Assumption: Skin Soil Loading (mg/cm2) **Cell: B7**

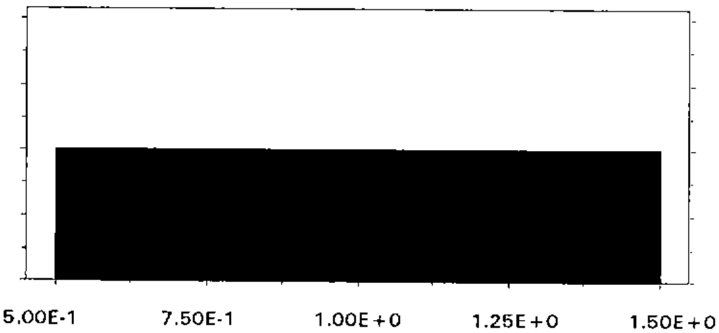
Uniform distribution with parameters:

Minimum	5.00E-01
Maximum	1.50E+00

Mean value in simulation was 1.00E+0

Assumption: Skin Soil Loading (mg/cm2) (cont'd) **Cell: B7**

Skin Soil Loading (mg/cm2)



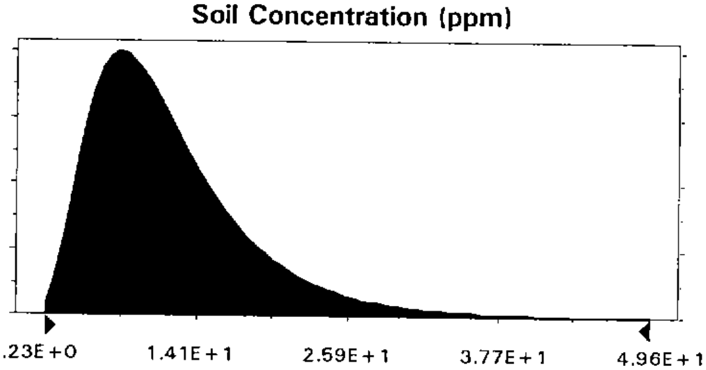
Assumption: Soil Concentration (ppm) **Cell: B6**

Lognormal distribution with parameters:

Mean	1.20E+01
Standard Dev.	6.65E+00

Selected range is from 1.00E+0 to 5.00E+1
Mean value in simulation was 1.20E+1

Soil Concentration (ppm)



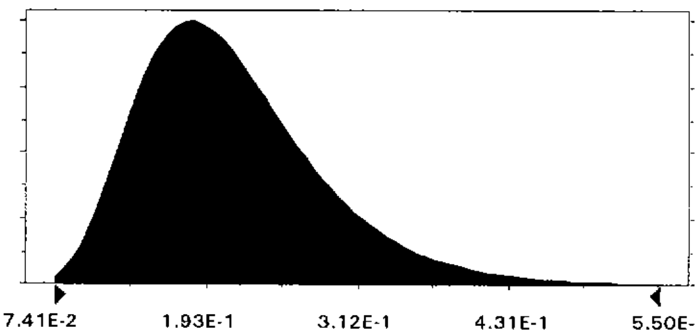
Assumption: Fraction of Skin Area Exposed **Cell: B5**

Lognormal distribution with parameters:

Mean	2.13E-01
Standard Dev.	7.33E-02

Selected range is from 5.00E-2 to 6.50E-1
Mean value in simulation was 2.14E-1

Fraction of Skin Area Exposed



Assumption: Dermal Absorption (%) **Cell: B8**

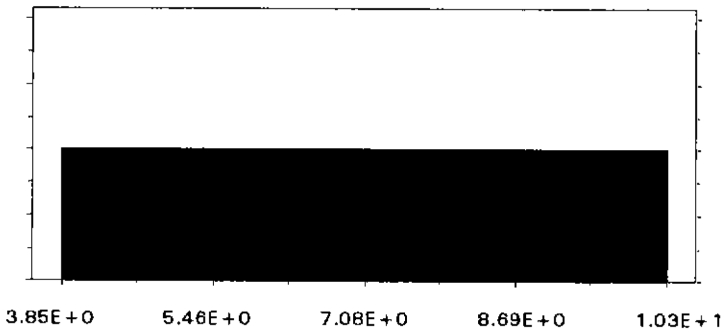
Uniform distribution with parameters:

Minimum	3.85E+00
Maximum	1.03E+01

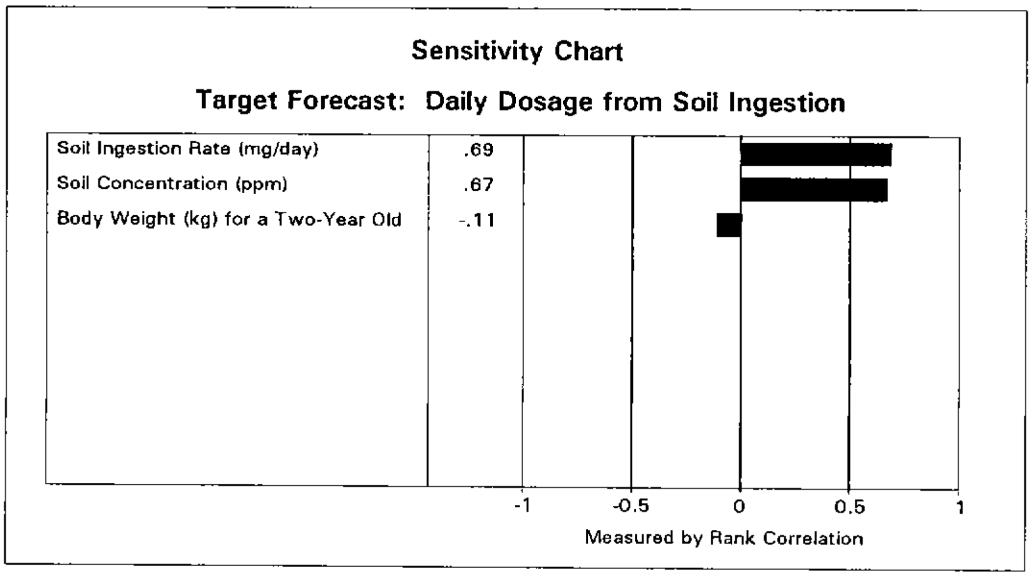
Mean value in simulation was 7.07E+0

Assumption: Dermal Absorption (%) (cont'd) **Cell: B8**

Dermal Absorption (%)



End of Assumptions

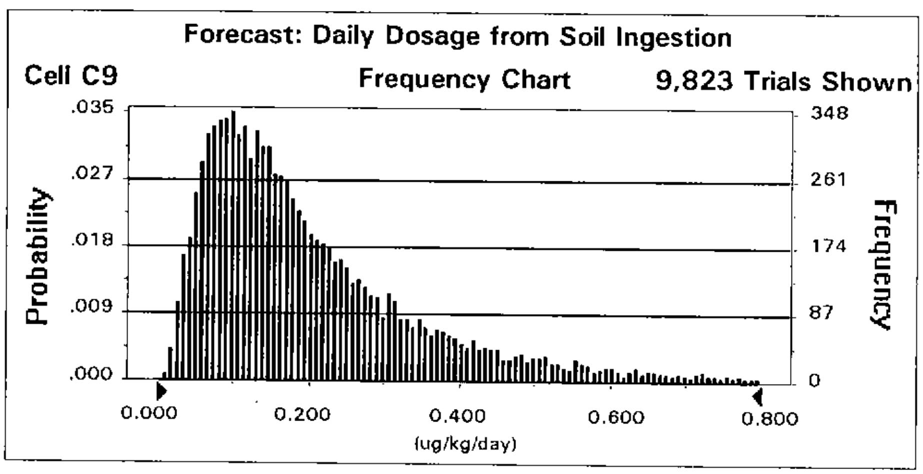

Sensitivity Chart
Target Forecast: Daily Dosage from Soil Ingestion
Soil Ingestion Rate (mg/day)
.69
Soil Concentration (ppm)
.67
Body Weight (kg) for a Two-Year Old
-.11
-1
-0.5
0
0.5
1
Measured by Rank Correlation

Forecast: Daily Dosage from Soil Ingestion **Cell: C9**

Summary:

Display Range is from 0.000 to 0.800 (ug/kg/day)
Entire Range is from 0.009 to 2.489 (ug/kg/day)
After 10,000 Trials, the Std. Error of the Mean is 0.002

Statistics:	Value
Trials	10000
Mean	0.220
Median (approx.)	0.165
Mode (approx.)	0.096
Standard Deviation	0.188
Variance	0.035
Skewness	2.739
Kurtosis	16.194
Coeff. of Variability	0.853
Range Minimum	0.009
Range Maximum	2.489
Range Width	2.479
Mean Std. Error	0.002



Forecast: Daily Dosage from Soil Ingestion (cont'd) **Cell: C9**

Percentiles:

Percentile	(ug/kg/day) (approx.)
0.0%	0.009
2.5%	0.037
5.0%	0.048
50.0%	0.165
95.0%	0.576
97.5%	0.725
100.0%	2.489

End of Forecast

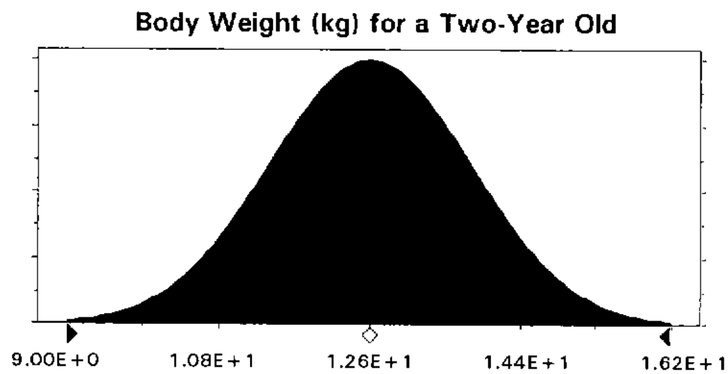
Assumptions

Assumption: Body Weight (kg) for a Two-Year Old **Cell: C6**

Normal distribution with parameters:

Mean	1.26E+01
Standard Dev.	1.20E+00

Selected range is from 9.00E+0 to 1.62E+1
Mean value in simulation was 1.26E+1



Assumption: Soil Ingestion Rate (mg/day) **Cell: C5**

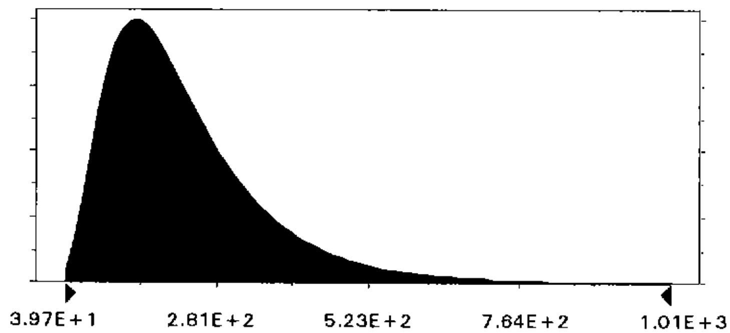
Lognormal distribution with parameters:

Mean	2.31E+02
Standard Dev.	1.34E+02

Selected range is from 1.00E+1 to 1.00E+4
Mean value in simulation was 2.31E+2

Assumption: Soil Ingestion Rate (mg/day) (cont'd) **Cell: C5**

Soil Ingestion Rate (mg/day)



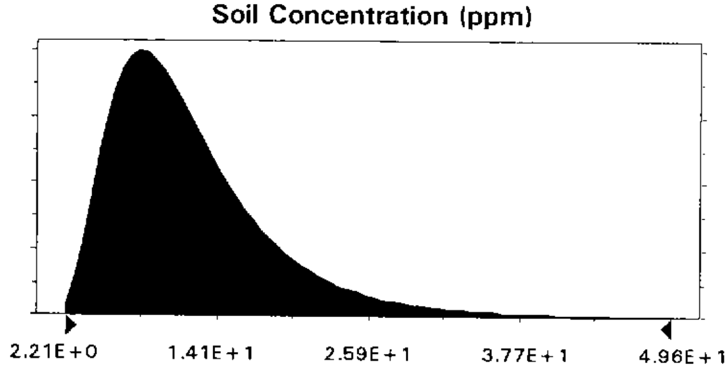
Assumption: Soil Concentration (ppm) **Cell: C3**

Lognormal distribution with parameters:

Mean	1.20E+01
Standard Dev.	6.65E+00

Selected range is from 1.00E+0 to 5.00E+1
Mean value in simulation was 1.19E+1

Soil Concentration (ppm)



End of Assumptions